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AUTOMATIC VEHICLE MONITORING SYSTEMS STUDY

Report of Phase 0

Vol. 1. Executive Summary

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PREFACE

This document on Automatic Vehicle Monitoring Systems presents the results of work supported by the National Science Foundation. It was sponsored under an interagency agreement with the National Aeronautics and Space Administration through Contract NAS 7-100. Points of view and opinions stated in this document are those of the authors and do not necessarily represent the official position of the sponsoring agency.

FOREWORD

This report was prepared for distribution to public safety planners for the purpose of providing them with a compact source of information regarding improvements in efficiency and cost benefits obtainable with various classes of operational and proposed automatic vehicle monitoring (AVM) systems. An AVM system can contribute to emergency patrol effectiveness by reducing response times and by enhancing officer safety as well as by providing essential administrative control and public relations information. This complete report and the Executive Summary (Vol. 1) were prepared by the Jet Propulsion Laboratory of the California Institute of Technology using the results of studies sponsored by the National Science Foundation.

Special computer programs are described which can simulate and synthesize AVM systems tailored to the needs of small, medium and large urban areas. These analyses can be applied by state and local law enforcement agencies and by emergency vehicle operators to help decide on what degree and type of automation will best suit their individual performance requirements and also the possible reduction in the number of vehicles needed which could substantially reduce operating expenses.

G. R. Hansen

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ABSTRACT

A set of planning guidelines is presented to help law enforcement agencies and vehicle fleet operators decide which automatic vehicle monitoring (AVM) system could best meet their performance requirements. Improvements in emergency response times and resultant cost benefits obtainable with various operational and planned AVM systems may be synthesized and simulated by means of special computer programs for model city parameters applicable to small, medium and large urban areas. Design characteristics of various AVM systems and the implementation requirements are illustrated and costed for the vehicles, the fixed sites and the base equipments. Vehicle location accuracies for different RF links and polling intervals are analyzed. Actual applications and coverage data are tabulated for seven cities whose police departments actively cooperated in the JPL study. Volume 1 of this Report is the Executive Summary. Volume 2 contains the results of systems analyses.

AUTOMATIC VEHICLE MONITORING SYSTEMS

I. INTRODUCTION

This document summarizes the results of a study undertaken by the Jet Propulsion Laboratory for the National Science Foundation to aggregate and analyze available information on Automatic Vehicle Monitoring (AVM) systems in such a way as to assist police or other agencies in making valid comparisons of competing AVM systems. In general, there were three tasks to be performed:

- (1) Compile a broad base of information on AVM systems and potential user cities.
- (2) Develop and adapt computerized techniques for analyzing the data, including cost-benefit comparisons.
- (3) Apply these techniques to the information base to produce useful numerical comparisons of AVM techniques and systems.

The distinction between AVM "techniques" and systems is frequently made in this document. The term "AVM technique" refers to the particular technology used to locate vehicles (vehicle instrumentation, radio beacons, signposts, etc.), while the term "AVM system" refers to the complete system that incorporates the technology (including vehicle and base station equipment, any fixed sites, and any communication links needed).

Task 1 involved an extensive review of the available literature on AVM systems, supplemented by information obtained directly from police department representatives of seven Southern California cities relating to the characteristics of their cities as well as of their police operations. Task 2 covered the development of several computer models and analytical techniques; special techniques were developed to predict vehicle interrogation times and system performance and cost for three hypothetical cities and then for the seven California cities in the User Group Advisory Committee. These analyses included cost-benefit analyses for all the techniques considered under a number

of assumptions as to the method of interrogating the vehicles which is the polling technique employed, message redundancy, and radio channel availability.

The preliminary conclusions that may be drawn from the results of the study are summarized in Sections 4 and 5. The principal conclusions of interest are the following:

- (1) A major determinant of the benefit of an AVM system is the location accuracy of the given system, which in turn is most strongly influenced by the polling interval (length of time required for the base station to receive location data on all vehicles deployed, before starting a new location cycle).
- (2) Small cities (those with a fleet of less than 50 vehicles), in general, do not benefit from any AVM system, while larger cities show a significant benefit for some types of system.
- (3) A wider variety of systems are economically feasible for real medium cities than for the large or small cities. These systems are from Class I, Kinematic Sensors and Class II, Autonomous Signposts which are defined in the text.
- (4) The large cities' choices which show substantial savings are from Class III, Special Radio Frequency Sites and Class IV, Monitored Signposts. Other classes show a much smaller saving in the large city application.

II. AVM SYSTEM DESCRIPTIONS

This study examined and analyzed thirty-six AVM techniques; the results of the analysis are presented for the individual techniques. As a framework for grouping this large number of techniques we have adopted a set of AVM classes defined in accordance with the effect on the urban environment of installing a given class of system. Four classes have been defined:

Class I. No modification to the urban environment

The class includes those systems in which all the necessary equipment is installed either in the vehicles or in the command center, with no other equipment required. Seventeen of the AVM techniques are included in this class, representing one of three operating principles:

- (1) The officer in the car sends position location messages to the command center (officer update).
- (2) The car contains equipment that automatically determines location from the motion of the car and encodes this data for transmission to the command center (Kinematic sensor).
- (3) The vehicle is located by the same navigation techniques used for aircraft, using existing navigational beacons or radio signals. Like the previous two principles, this one also requires use of the radio frequency (RF) link between command center and vehicle (Wide Area Navigation).

Class II. Autonomous Signposts

The operation of this class of AVM system depends on the installation of numerous signposts throughout the area to be covered. They are called autonomous because they are not linked to the command center; they communicate their identify (and hence location) to passing vehicles, which in turn relay the data automatically to the command center over the RF link.

Class III. Sparsely Distributed Special RF Sites

In this class are those systems that require the installation of relatively few special-purpose fixed RF sites, each of which either broadcasts or receives over a relatively large urban area 3 to 7 miles in radius. The only role of the vehicle is to broadcast a signal coded with its identity; location information is sent from the sites to the base station directly with no added load on the RF channels.

Class IV. Monitored Signposts

These systems require about as many signposts as the Class II systems, but automatically sense the identity of passing vehicles and transmit this information over separate links to the command center. Their attraction is also that no use of the RF command links is required.

The 36 different techniques, grouped into the above classes, are briefly described in Table 1. As will be shown, they vary considerably in the accuracy with which they can locate police vehicles. Even for a given technique, this accuracy varies widely with the number of vehicles deployed in those cases where the vehicle-to-command center RF link must be used.

The reason for this variation is that the polling interval is longer for a larger number of vehicles. The polling interval is the length of time between succeeding "fixes" of a given vehicle. Each vehicle repeats its location message only after all the others have been similarly "polled," and the more vehicles there are the longer this interval will be. Since the vehicle is normally moving all the time, its location will be more and more uncertain as the interval grows longer.

Table 1. Summary Descriptions of AVM Techniques

Technique	Description
CLASS I – <u>No modification to the urban environment</u>	
<u>Officer Update</u>	
1. Keyboard entry	Officer in vehicle transmits vehicle location to command center as a digital message. He may use a keyboard and a set of location codes or press a stylus on a map of the area, with the location being automatically encoded by means of a grid under the map.
2. Stylus map	
<u>Kinematic Sensors</u>	
3. Two accelerometers	Two accelerometers measure the rate of change of velocity (including both speed and direction) of the vehicle; this data is used to update the vehicle location from a known initial location. The location is transmitted when the vehicle is polled.
4. Laser velocimeters	The principle is the same as (3) above, but the velocity measurement is made by two devices that indicate velocity change by a moving speckle pattern detected by a photodetector. The vehicle location is maintained in a small computer on the vehicle and updated at frequent intervals.
5. Ultrasonic velocimeters	The operating principle is the same, except that the determination of velocity change is made by the reflection of ultrasonic waves from the road. All three velocimeter techniques use one to measure velocity change in the fore-and-aft direction and one for the transverse direction.
6. Odometer-Compass	This is a simple "dead reckoning" technique such as used on ships. An odometer continuously measures the distance traveled, and a compass detects changes in direction. Both types of data are used to update vehicle location with reference to a known initial location.
7. Compass-Laser velocimeter	Same as above, but with a laser velocimeter replacing the odometer.
8. Compass-Ultrasonic velocimeter	Same as compass-odometer but with the ultrasonic velocimeter replacing the odometer.

Table 1. Summary Descriptions of AVM Techniques (contd)

Technique	Description
<u>Wide-area Navigation</u>	
9. OMEGA	This is a widely-used navigation technique for aircraft and ships, using time-multiplexed signals at very low frequency (VLF) in the range of 10-13 kHz. The signals are transmitted from multiple sites (already existing throughout the world), and the location of the vehicle is determined from the intersection of lines from the sites.
10. LORAN	This widely-used navigation system is similar to OMEGA, but uses pulse-coded signals near 100 kHz.
11. DECCA	This system, also in common use, operates on the same principle as OMEGA and LORAN, but uses phase differencing of continuous waves near LORAN frequencies.
12. AM Stations	A similar principle can be employed in determining location by means of the carrier signals from three broadcasting stations spaced around a city. This scheme measures the motion of the vehicle from a known initial position.
13. Differential OMEGA	This modification of the OMEGA techniques uses a fixed receiver at a precisely known location to remove the ambiguities from the normal OMEGA "fix."
14. Differential LORAN	This applies the same principle to the LORAN system.
15. Differential AM stations	This uses a fixed receiver to remove local anomalies and the effects of the AM stations not being "locked" to one another.
16. Relay OMEGA	In this version of the OMEGA system, the vehicle rebroadcasts the raw OMEGA signals on another frequency, and all measurements and computations are done at the base station.
17. Relay LORAN	This is a similar scheme for the LORAN system; it requires compression of the LORAN signal for it to be transmitted over the voice channel.
NOTE: All the wide-area navigation systems require specialized equipment on the vehicle to receive and encode the data which is then transmitted to the base station for computation of the vehicle location.	

Table 1. Summary Descriptions of AVM Techniques (contd)

Technique	Description
CLASS II - <u>Autonomous Signposts</u>	
18. Buried Loops	This technique, analyzed in Volume 2, operates by having the vehicle, equipped with an undercar antenna, pass over and excite the loops to obtain a response containing the coded location of the loop.
19. Reflecting Signs	Coded reflective wayside signs are placed throughout the area, and a sensor on the vehicle continually interrogates the area; when a sign is encountered, its coded location is received by the vehicle equipment and transmitted to the base station.
20. Reflecting Road	This technique is similar to the above except that the coded reflecting pattern is painted on the roadway.
21. X-band Post	This is one of the group of RF signpost systems. In all such systems the signposts are located at fairly close intervals (one or a few blocks) and continuously broadcast short-range signals containing their coded location. The vehicle is equipped with a special receiver and decoder; the decoded data is transmitted to the base station over the vehicle radio.
22. High Frequency (HF) or Very High Frequency (VHF) Post	This system uses the same principle at different frequencies, with different results in terms of cost and accuracy.
23. Low Frequency Post	This system also differs primarily in terms of cost and performance from the other RF post systems. All such systems require a power source in each post.
24. Light Infrared Post	Either visible or infrared coded flashing lights on signposts can be used in a similar manner to the RF posts, with the advantage of not adding to general RF congestion and interference. They may be subject to weather conditions, such as heavy fog or rain.
25. Buried Magnets	A set of permanent magnets buried in the roadway with their poles sequenced in a coded pattern can serve as passive location identifiers. A sense coil in the vehicle detects the reversals of polarity and these are decoded into the location.

Table 1. Summary Descriptions of AVM Techniques (contd)

Technique	Description
26. Ultrasonic Post	Ultrasonic waves can be used instead of RF or light waves in the same manner, using a horn antenna to focus the signals in the desired direction.
27. Traffic Sensor	Buried active antennas are presently used as traffic-present sensor loops to control signals, and experiments are under way to use them for automatic toll charging of buses. In an AVM system the loops continually radiate, and when an equipped vehicle passes over them it detects the location code of the loop.
CLASS III - <u>Sparsely distributed special RF sites</u>	
28. Narrowband FM Phase	This system is called narrowband because the signal can fit into a standard FM voice channel of 25 kHz. Like the other trilateration systems, it defines location by the intersection of three lines (as in the wide-area navigation systems). The lines are defined by measuring the time-of-arrival (TOA) of a signal from the vehicle at multiple fixed sites. In this system the vehicle is located by its transmitting an FM signal with an audio tone modulating the carrier. The relative phase of the audio tone is measured at the receiving sites to determine range difference and hence location.
29. Wideband FM Phase	This system uses the same principle, but requires four times the bandwidth (100 kHz).
30. Pulse Time-of-Arrival	This system also uses the same principle, but instead of an audio tone it uses the time-of-arrival of a carrier pulse. It can use up to 10 MHz of bandwidth.
31. Noise Correlation	This system uses interferometer techniques, with the vehicle transmitting a noise-modulated carrier. Time-of-arrival differences would be established by computation of the correlations of the noise signals.
32. Direction Finder	This is a triangulation system, with at least three fixed sites measuring the bearing angle to the vehicle transmitting a coded beacon signal. The normal vehicle transceiver would be used for this purpose, as it would for (28) above. All the other Class III systems would require an additional special AVM transmitter.

Table 1. Summary Descriptions of AVM Techniques (contd)

Technique	Description
CLASS IV – <u>Monitored Signposts</u>	
33. Traffic Loops	This system is the inverse of (27) above, in that it also uses existing traffic-presence sensors buried in the roadway. In this scheme, the vehicle carries an undercar antenna continuously radiating its ID code; the buried traffic loop detects this code and transmits it (with its own ID) to the base station. If traffic signals are centrally controlled, there will already be communication lines from these sensors to a central point, and in any case power will be available from the supply to the traffic signals.
34. Wayside Radio	Like the other Class IV systems, this one removes the transmission of vehicle location data from the RF link between vehicle and base station. The vehicle broadcasts its ID continually (the frequency may be citizen's band, X-band, or MF-band) and the posts are equipped with receivers that receive the signal when the vehicle is in close proximity. The vehicle ID is transmitted over land lines to the base station.
35. Photo/Infrared Detector	This system operates like the comparable Class II system, but with the information flow going from the vehicle (with its coded flashing light) to the post (with its sensor and decoder).
36. Ultrasonic Detector	This system also operates like its Class II counterpart but with the vehicle transmitting and the post receiving.

The polling interval depends on the number of cars, but in those systems where the AVM information is not transmitted over the base-station-to-vehicle RF link (Classes III and IV) the interval is so short that it does not limit system accuracy for any number of cars. Where the base station-to-vehicle link is used to transmit AVM data to the base station (Classes I and II), the AVM messages must contend for air time along with all the other messages from the vehicle. In this case the polling interval, and hence the accuracy, varies considerably with the number of vehicles. One solution to this problem where there are large fleets of vehicles would be to have a separate RF channel for AVM information only. We have analyzed this case and found that the separate channel can improve system accuracy dramatically for large fleets (but of course with added expense and requirement for channel capacity).

As a basis for the results to be presented later, it will be useful to distinguish between technique accuracy and system accuracy. Each of the techniques has an inherent uncertainty radius in the location of the vehicle; this is the precision with which it could locate the vehicle if there were only one vehicle to locate and it were standing still. This is the ultimate accuracy of the technique, and is of only limited interest because any technique that is used must be incorporated into a system consisting of many moving vehicles and their equipment, any stationary sites, the communication links, and the equipment and processing at the base station. The accuracy obtainable with the complete system is the parameter of interest and is presented in the summary results in this volume. Data on ultimate accuracy will be found in Volume II.

III. VEHICLE POLLING TECHNIQUES

Vehicle polling is the process by which the location data for each vehicle is caused to be transmitted to the base station. In the case of Class IV techniques (monitored signposts), this process is carried out automatically by landlines and does not use the RF link between vehicle and base station; the signposts either transmit their data automatically or they are automatically interrogated by the base station computer at a very rapid rate. The term polling as used here does not apply to these systems. The basic polling techniques are:

- (1) Synchronous Polling, in which each vehicle is assigned a time slot in the polling sequence and automatically transmits its location data at that time. This means that the vehicle equipment must keep track of the time from the start of the polling sequence. The start of the sequence is transmitted periodically to each vehicle to correct its internal clock. In a variation of this technique, the base station can change the sequence of vehicles by transmitting the new sequence to the vehicle data processor; this is referred to as synchronous polling with command capability. This technique is generally used only with Class III systems (relatively few fixed RF sites).
- (2) Commanded or Random Access Polling, in which the base station interrogates the vehicle equipment whenever it requires the location of that vehicle. This is the most flexible technique, but uses more RF time than the synchronous technique.
- (3) Volunteer Polling, in which the vehicle equipment checks to be sure that the channel is clear before transmitting its location data. The base station does no interrogating. This technique is usually considered only for low-density Class II systems (autonomous signposts).

To examine the effects of these different techniques, we calculated the numbers of cars per second that could be polled by each technique. Since any delays in the polling process will tend to reduce the numbers of cars that can be handled by an RF channel, we introduced a factor called "turn-on time" that lumps together all sources of delay other than channel congestion (which is reflected in later analyses). The values chosen covered enough range to reflect the difference between (two RF channels) radios with separate antenna circuits and one RF channel radios with electromechanical antenna transfer relays. In all cases where the existing two-way radio is to be used, some speed-up modifications are required for AVM applications; these cover changes to antenna switching, transmitter stabilization time, and squelch delay. Without these, the "guard times" (unused time before and after the actual transmissions to allow for uncertainties in synchronization) would increase the time required for the complete polling sequence to unacceptable values.

We assumed a message rate of 1500 bits/sec. Actual length of the message depends on which type of system is used and on the size of the geographical area; with a signpost system, for example, the message must be longer if there are many more signposts, and the ID of a car is longer if there are a large number of cars. We also made the calculations for both simple (each message transmitted one time) and redundant (each message transmitted twice) message transmission, since both techniques are in common use.

Typical results are summarized in Table 2, which shows the number of cars per second that could be handled by the various groups of techniques. This table shows the results for a turn-on time of 0.03 seconds; calculations were made for five different times (0., 0.01, 0.03, 0.1, and 0.3 seconds) and the complete results are given in Volume II. The effect of simple and redundant transmissions was also calculated, as was that of a longer location message (in the case of Class II techniques). Some general conclusions that can be drawn from these analyses follow:

**Table 2. Polling Performance of AVM Systems
(0.03 Second Turn-on Time) Using
Different Polling Techniques**

Type of System	Cars handled per second		
	Synchronous	Volunteer	Random
Officer update	27	21-23	13-14
Kinematic sensors	26	22	13-14
Wide area navigation (except relay)	20-27	18-23	12-14
Wide area navigation relay systems	1-3	1-3	1-3
Autonomous signposts	24-29	21-27	13-15

- (1) Longer turn-on times tend to reduce the effects of all variables (AVM technique, polling technique, message redundancy, message length). At 0.3 seconds, for example, the numbers of cards handled under any set of conditions is 2, 3, or 4 per second; this is an unacceptably slow rate.
- (2) Turn-on time is an important variable; with a turn-on time of 0.1 second, for example, the rates given in Table 2 are roughly halved.
- (3) The various AVM techniques do not show a large range of difference with respect to polling performance, except for the two relay techniques (relay OMEGA and relay LORAN); these are always between 1 and 3 cars per second for any turn-on time and are consequently of no interest for practical AVM systems. As noted under (1) above, the differences among techniques diminish with longer turn-on times.
- (4) Redundant message transmission reduces the handling capacity to about 80 per cent of the single-transmission rate at the 0.03

second turn-on time shown in Table 2. The reduction is more marked (to about 65 per cent) at 0.01 second but virtually disappears at 0.1 second.

- (5) For Class II systems with autonomous signposts, the message length has a direct effect on performance; doubling the length cuts the number of cars handled by about half.
- (6) Turn-on time becomes the dominant factor for values above 0.03 second because the normal polling message consists of about 20 bits, taking 0.013 second to transmit at the bit rate we assumed. The turn-on time at 0.03 second is thus already twice the transmission time, and if it becomes any longer, it is by far the dominant factor in polling performance.

The results given above cover only Class I and Class II systems, which use the vehicle-to-base station RF link. Class III systems locate vehicles by radio signals, but do not use the regular RF communications link, while Class IV systems use no RF links at all.

IV. AVM COST BENEFIT ANALYSIS

A. COST ELEMENTS

The first step in determining the cost of AVM systems is to determine the costs of the individual elements of the system. These are given in detail in Volume 2. Table 3 summarizes the elements of systems based on the different AVM techniques, grouped into vehicle equipment, base station equipment, and equipment at other locations (signposts or fixed RF sites). Note that no cost is assigned to the existing communication system, which is in place already, except for the speed-up modifications to vehicle radios that were mentioned earlier. Those systems using wide-area navigation beacons also incur no cost for these beacons, which are in place and operating for purposes of aircraft navigation.

Table 4 summarizes equipment costs (including operations and maintenance of the equipment) for the different techniques, grouped into the same categories. All cost estimates in this report are based on 1974 prices. The costs in Table 4 are unit costs (per car, signpost, etc.) and therefore do not indicate the total cost of an AVM system. For example, fixed site cost per unit for Class III systems are much higher than for Class II or IV systems on a unit basis, but a complete system would require hundreds of signposts and only a few fixed RF sites.

B. SYSTEM COSTS

As a basis for estimating total system costs for the various AVM techniques, we defined three "model" cities: small, medium, and large. The medium city is ten times the size of the small one and the large city is ten times the size of the medium city. This provides a range of sizes that serves to indicate the effect of size on overall costs as well as on system performance.

Table 3. Elements of AVM Systems for Different Techniques

TECHNIQUE	Existing communication system	Data Encoder	Sensor/sensors	Data Processor*	Special AVM transmitter/beacon	Navigation beacon receiver	BASE STATION	Existing communication system	Vehicle Location Computer	Telemetry data and polling system	AVM land line data links	OTHER LOCATIONS	Existing navigation beacons	Autonomous signposts	Fixed synchronized HF sites	Monitored signposts	Existing AM stations
CLASS I																	
1 KEYBOARD	X	X					X	X	X	X							
2 STYLUS MAP	X	X					X	X	X	X							
3 2 ACCELEROMETERS	X	X	X	X			X	X	X	X							
4 LASER VELOCIMETER	X	X	X	X			X	X	X	X							
5 ULTRASONIC VELOCIMETER	X	X	X	X			X	X	X	X							
6 COMPASS/ODOMETER	X	X	X	X			X	X	X	X							
7 COMPASS/LASER VELOCIMETER	X	X	X	X			X	X	X	X							
8 COMPASS/ULTRASONIC VELOCIMETER	X	X	X	X			X	X	X	X							
9 OMEGA	X	X		X		X	X	X	X	X	X	X					
10 LORAN	X	X		X		X	X	X	X	X	X	X					
11 DECCA	X	X		X		X	X	X	X	X	X	X					
12 AM STATIONS	X	X		X	X		X	X	X	X	X						X
13 DIFFERENTIAL OMEGA	X	X		X		X	X	X	X	X	X	X					
14 DIFFERENTIAL LORAN	X	X		X		X	X	X	X	X	X	X					
15 DIFFERENTIAL AM STATIONS	X	X		X	X		X	X	X	X	X	X					X
16 RELAY OMEGA	X	X		X		X	X	X	X	X	X	X					
17 RELAY LORAN	X	X		X		X	X	X	X	X	X	X					
CLASS II																	
18 DIURID LOOPS	X	X	X				X	X	X	X			X				
19 REFLECTING SIGNS	X	X	X				X	X	X	X			X				
20 REFLECTING ROAD	X	X	X				X	X	X	X			X				
21 X-BAND POST	X	X	X				X	X	X	X			X				
22 HF OR VHF POST	X	X	X				X	X	X	X			X				
23 LF POST	X	X	X				X	X	X	X			X				
24 LIGHT/IR POST	X	X	X				X	X	X	X			X				
25 BURIED MAGNETS	X	X	X				X	X	X	X			X				
26 ULTRASONIC POST	X	X	X				X	X	X	X			X				
27 TRAFFIC SENSOR	X	X	X				X	X	X	X			X				
CLASS III																	
28 NARROWBAND FM PHASE	X	X					X	X	X	X			X				
29 WIDEBAND FM PHASE		X		X			X	X	X	X			X				
30 PULSE TIME OF ARRIVAL		X		X			X	X	X	X			X				
31 NOISE CORRELATION		X		X			X	X	X	X			X				
32 DIRECTION FINDER	X	X					X	X	X	X			X				
CLASS IV																	
33 TRAFFIC LOOPS				X			X	X	X								X
34 WAYSIDE RADIO				X			X	X	X								X
35 PHOTO/IR DETECTOR				X			X	X	X								X
36 ULTRASONIC DETECTOR				X			X	X	X								X

* In those systems where location data is received on the vehicle, the location may be computed on the vehicle computer and transmitted to the base station, or the raw data may be transmitted to the base station, where the computation is performed.

Table 4. Estimated Costs of AVM Systems (1974 prices)

TECHNIQUE	UNIT COSTS, DOLLARS		FIXED SITES		BASE STATION			
	VEHICLE				Non-recurring [®]			Recurring [†] (All)
	Non-Recurring	Recurring [†]	Non-Recurring	Recurring [†]	Small	Medium	Large	
CLASS I								
KEYBOARD	170	15	0	0	53	73	103	100
STYLUS MAP	2785	25	0	0	53	73	103	100
2 ACCELEROMETERS	1700	100	0	0	78	98	143	100
LASER VELOCIMETER	1915	150	0	0	78	108	143	100
ULTRASONIC VELOCIMETER	870	150	0	0	78	108	143	100
COMPASS/ODOMETER	1485	40	0	0	78	108	143	100
COMPASS/LASER VELOCIMETER	2005	90	0	0	78	108	143	100
COMPASS/ULTRASONIC VELOCIMETER	1685	90	0	0	78	108	133	100
OMEGA	2780	75	0	0	63	93	123	100
LORAN	2880	75	0	0	63	93	123	100
DECCA	1210	75	0	0	63	93	123	100
AM STATIONS	450	60	0	0	63	93	123	100
DIFFERENTIAL OMEGA	2780	75	0	0	63	93	123	100
DIFFERENTIAL LORAN	2880	75	0	0	63	93	123	100
DIFFERENTIAL AM STATIONS	515	60	0	0	63	93	123	100
RELAY OMEGA	605	100	0	0	63	93	123	100
RELAY LORAN	655	100	0	0	63	93	123	100
CLASS II								
BURIED LOOPS	185	15	25	0	53	73	103	100
REFLECTING SIGNS	630	20	85	5	53	73	103	100
REFLECTING ROAD	185	15	35	20	53	73	103	100
X-BAND POST	210	10	275	15	53	73	103	100
HF OR VHF POST	195	10	145	15	53	73	103	100
LF POST	195	15	170	15	53	73	103	100
LIGHT/IR POST	180	25	155	25	53	73	103	100
BURIED MAGNETS	145	0	6	0	53	73	103	100
ULTRASONIC POST	220	25	170	10	53	73	103	100
TRAFFIC SENSOR	185	10	135	0	53	73	103	100
CLASS III								
NARROWBAND FM PHASE	265	25	5025	505	64	131	208	100
WIDEBAND FM PHASE	3055	25	13070	500	78	133	183	200
PULSE TIME OF ARRIVAL	2725	25	16500	500	148	333	363	175
NOISE CORRELATION	885	25	11000	2000	148	333	363	175
DIRECTION FINDER	50	0	27525	1205	43	73	133	150
CLASS IV								
TRAFFIC LOOPS	145	10	291	14	53	73	103	100
WAYSIDE RADIO	115	10	286	29	53	73	103	100
PHOTO/IR DETECTOR	185	15	296	29	53	73	103	100
ULTRASONIC DETECTOR	190	15	306	29	53	73	103	100

[†] Recurring costs are in dollars per month.

^{*} Figures in these columns are in thousands of dollars.

The city parameters that affect system costs are as follows:

- (1) City Shape. In recognition of the fact that cities are seldom square or circular, as often assumed for analysis, we assumed that our model cities were rectangular, with one dimension twice the other. The shape of actual cities was used in the analyses of Section 5, relating to the seven cities of the User Group Advisory Committee (UGAC).
- (2) Area. The area of a city naturally affects the size of the fleet as well as the number of fixed sites needed. We used areas of 10,000, and 1000 square kilometers (4, 40 and 400 square miles), which are representative of the cities in the UGAC group.
- (3) Population. We assumed that population was directly related to area and took a value of 3000 persons per square kilometer; this is an average representation of the population densities in the UGAC cities.
- (4) Vehicle Fleet Size. The number of vehicles to be monitored clearly has a direct effect on system cost. We have assumed that half the total fleet would be in service or on patrol at any given time. The fleet size is proportional to area.
- (5) Intersections. Vehicle location information for dispatcher use is most useful in terms of named intersections, and the number of intersections affects AVM system costs primarily for the sig. post systems (Classes II and IV) where signposts are placed at intersections. The numbers used are based on actual measurements of random areas of the UGAC cities. Values assumed are 30 intersections per square kilometer for 75 percent of the area and 50 per square kilometer for the remainder.
- (6) Road Distance. Blocks are assumed to be rectangles twice as long as wide, with an average of 2.4 lanes per road segment.
- (7) Telephone Line Distance. Class IV systems use telephone lines to transmit data to the base station, and line rent costs are included for these systems. Sensors are assumed to be equally divided among lines, with a maximum of 100 sensors for each telephone "party" line. The lines are assumed to parallel the long streets,

making the total line mileage about two thirds the total road distance.

- (8) Building Distribution and Topography. In a real system, costs may be affected by the locations of high-rise buildings and hills or valleys. We have assumed a flat topography and uniform low-rise construction.
- (9) Radio Characteristics. It has been assumed that the location messages did not need to contend for channel time, and as noted above, the vehicle radios are assumed to have been modified for AVM purposes.

The parameters assumed for the three model cities are given in Table 5.

The parameters of the AVM system itself also affect system costs. One of these parameters is the performance of the system. On the basis of test data, prototype demonstrations, and performance estimates by developers and others, we assembled the performance data shown in Table 6. For the Class II and IV (signpost) systems, the term "accuracy" is inappropriate and the radius of detection of the signposts is given in this column. Accuracy values are needed in the analysis of benefits, although they do not directly affect costs. The message length is needed to determine polling interval, and the fix time (length of time required for the vehicle or fixed site to receive or generate new location data) is a factor in how often the vehicle location is updated (and hence accuracy). For the signpost systems, the indicated time is that required for at least two location messages to be generated while the vehicle is moving at maximum speed. In Class II systems, the time shown is only the time of transmission of a location signal to the special RF site.

As we have already seen, the polling interval has a strong influence on system performance, which in turn affects the calculation of benefits. Polling intervals are given for all techniques in Volume 2 and are summarized in Table 7. Only the ranges for all techniques are shown, since the differences are generally not large enough to be significant. An exception is the two relay systems (relay OMEGA and relay LORAN), where the polling interval is

Table 5. Model City Parameters that affect AVM Costs

Parameter	Small	Medium	Large
Area, km ²	10	100	1000
Dimensions, km	2.2 x 4.5	7.1 x 14.2	22.3 x 44.7
Vehicles, patrol/total	5/10	50/100	500/1000
Intersections*	350	3500	35000
Road segments lanes	1600	16800	168000
Road distance, km	125	1245	12450
Telephone lines, km	83	828	8275
Population	30,000	300,000	3,000,000

*Based on 25/75% ratio of 50/30 blocks/km² in the urban area.

Table 6. Location Performance Parameters for all AVM Classes and Systems

Technique	Accuracy or Radius	Value used, (m)	Location Data, (bits or BW)	Fix Time, (sec)
CLASS I AVM	Accuracy			
Keyboard update	10-100 m	(33)	6-20 bits	2-5 s
Stylus map update	30 m	(30)	14-20	3
2-Accelerometers	2% dist	(34)	14	0.3
Laser velocimtr	0.5% dist	(13)	16	0.3
Ultrasonic velo	3% dist	(40)	14	0.3
Compass/odometer	1% dist	(20)	14	0.3
Compass/laser vel	0.6% dist	(15)	14	0.3
Cmpss/u-sonic vel	0.8% dist	(17)	14	0.3
OMEGA navigation	1600 m	(1600)	27	3-10
LORAN navigation	0.4 m/km	(160)	32	0.06-.2
DECCA navigation	0.5 m/km	(200)	30	0
AM-Stations nav	150-250 m	(200)	12	0-3
Diff OMEGA nav	160 m	(160)	27	3-10
Diff LORAN nav	120-400 m	(400)	32	0.06-.2
Diff AM-Stations	150-250 m	(250)	21-32	0-3
Relay OMEGA nav	200-600 m	(500)	3 kHz BW	3-10
Relay LORAN nav	800 m	(800)	10 kHz BW	0.06-.2
CLASS II AVM	Radius m			
Buried res loops	10	—	10-18 bits	1-2 s
Reflecting signs	10	—	10-18	1-2
Reflecting road	3	—	10-18	1-2
X-Band signposts	12-100	—	9-17	1-2
HF, VHF signpost	15-100	—	7-15	2-5
LF Signposts	100	—	9-17	1-2
Light/IR post	30	—	9-17	1-2
Buried magnets	10	—	10-18	1-2
Ultrasonic post	20	—	9-17	1-2
Traffic sensor	10	—	10-18	1-2
CLASS III AVM	Accuracy			
Nar-band FM phase	800-1300 m	(1000)	3 kHz BW	0.015 s
Wid-band FM phase	1000-1500	(1200)	15-40 kHz	0.01
Pulse T-O-Arrival	100 m	(100)	10 MHz	0.0001
Noise correlation	100 m	(100)	5-10 MHz	0.001
Direction finder	3% dist	(700)	3 kHz	0.2-1
CLASS IV AVM	Radius, m			
Traffic loops	10	—	N/A	1-2 s
Wayside radio	100	—	N/A	1-2
Photo/IR detect	30	—	N/A	1-2
Ultrasonic detect	20	—	N/A	1-2

Table 7. Polling Performance for Model Cities

City Size	Time to Poll Entire Fleet, seconds	
	Synchronous/Volunteer	Random
Small	0.53 - 0.62	1.06 - 1.13
Medium	5.36 - 6.30	10.83 - 11.53
Large	53.67 - 64.00	110.33 - 117.33

roughly 200 times those for the other systems, and the values are not included in the table. For the other techniques, the polling interval for the best technique is generally at least 80 percent of that for the worst system.

The figures in Table 7 are for a single transmission of each location message. For redundant transmissions the values are about 10 percent higher.

The accuracy or radius shown in Table 6 for the various techniques does not indicate the actual uncertainty of knowledge of the vehicle position. This uncertainty is affected by the polling interval and the vehicle's speed for Class I and III systems, since the location of the vehicle to the given accuracy was known only at the time it was polled. The faster it is moving, the farther it is from that location. Since the transmission of location data may be subject to equipment delays and channel congestion delays, it is possible for the vehicle to be at some distance from its last known location before a new location determination is made (and the new location is again subject to the same uncertainties).

Similar problems arise with signpost systems. If signposts are located at every intersection the vehicle's location is at best known to within one block at the time the data is transmitted; however, this is a very high density for a signpost system. Considerable savings can be realized by placing

them every other block or at even greater intervals, but at the expense of greater uncertainty in vehicle location. There is also a probability that a vehicle may pass the location of a signpost without triggering a location message and this probability needs to be estimated in calculations of system accuracy. One drawback of signpost systems is that the vehicle can be located only if it is in an area with signposts, while the other classes (I and III) of systems can locate a vehicle anywhere within the area covered.

C. COST BENEFIT ANALYSIS

As a rough basis for estimating costs versus benefits of AVM systems, a computer program was developed to compute the benefits of an AVM system in terms of the number of cars saved. It is assumed that if the dispatcher knows the location of the vehicle with sufficient accuracy, he will be able to dispatch the nearest vehicle consistently and that consequently travel times will be reduced and a smaller number of vehicles will be able to provide the same service. Earlier studies discussed in Volume 2 have indicated possible savings of about 7 to 10 percent if the vehicle location is known to within about one fifth of the length of one side of a beat. For the purposes of this study, a 7 percent increase in efficiency is assumed for a perfect system, with the efficiency decreasing linearly to zero at an AVM accuracy of one-fifth of the average beat side length (determined by dividing the area by the number of vehicles deployed and then ascertaining square beat dimensions). The number of cars saved is determined by multiplying the percent improvement in efficiency by the total number of vehicles deployed. Cost savings are estimated at the rate of \$150,000 per car per year (5 salaries plus 100% overhead, 1974 rates).

The summary results of these calculations are given in Table 8 for a five-year period of operation. The cost saving calculation is performed only if a saving in the number of cars is indicated (fractional cars are allowed in the calculation). No calculation is performed if no car saving is indicated. The cost benefit is calculated as a straightforward multiplication of the cars saved times the annual value of the car minus the O&M costs of the given AVM technique. The saving is positive only if the value of the saved cars exceeds the total O&M costs. Thus a negative entry in the five-year saving column means that the cost exceeded the saving, while a zero entry means that there were no savings at all.

The major conclusions to be drawn from Table 8 are:

- (1) No small city shows a net cost benefit for an AVM system using any of the techniques.
- (2) None of the wide area navigation systems show a net cost benefit for any size city. This results from their generally poor accuracy.
- (3) No system with an accuracy poorer than 100 meters shows a net cost benefit for any size city except the pulse time-of-arrival and noise correlation systems in a large city.
- (4) Although the addition of a second RF channel in a large city can improve the accuracies of many systems, the improvement is not enough to bring the accuracy into the range needed for a net cost benefit.
- (5) Cost savings of less than a million dollars are probably within the range of error of this rough computation and therefore should not be considered significant in comparing techniques. The only systems showing net cost savings of more than a million dollars are the Class IV systems (except wayside radio) for the medium and large cities and the pulse time-of-arrival and noise correlation systems for large cities.

Table 8. Cost Benefit Analysis for Model Cities

Technique	Small City			Medium City			Large City			Large City with Two RF Channels		
	Accuracy, Meters	Vehicles Saved	5-Year Saving, K\$	Accuracy, Meters	Vehicles Saved	5-Year Saving, K\$	Accuracy, Meters	Vehicles Saved	5-Year Saving, K\$	Accuracy, Meters	Vehicles Saved	5-Year Saving, K\$
CLASS I												
Keyboard	86	0.2	-355	199	1.0	240	2059	0	0	917	0	0
Stylus Map	75	0.9	-355	206	0.9	160	2133	0	0	945	0	0
2 Accelerometers	89	0.2	-355	203	1.0	200	2095	0	0	931	0	0
Laser Velocimeter	34	0.3	-285	199	1.0	175	2058	0	0	917	0	0
Ultrasonic Velocimeter	101	0.2	-360	204	1.0	175	2196	0	0	935	0	0
Compass/Odometer	49	0.2	-355	199	1.0	230	2062	0	0	918	0	0
Compass/Laser Velocimeter	38	0.3	-200	198	1.0	205	2044	0	0	912	0	0
Compass/Ultrasonic Velocimeter	43	0.2	-355	199	1.0	205	2052	0	0	915	0	0
OMEGA	3698	0	0	4077	0	0	4083	0	0	3966	0	0
LORAN	370	0	0	408	0	0	2411	0	0	1194	0	0
DECCA	446	0	0	492	0	0	2403	0	0	1190	0	0
AM Stations	444	0	0	490	0	0	2136	0	0	965	0	0
Differential OMEGA	370	0	0	408	0	0	2351	0	0	1163	0	0
Differential LORAN	960	0	0	1131	0	0	2312	0	0	1144	0	0
Differential AM Stations	537	0	0	592	0	0	2371	0	0	1173	0	0
Relay OMEGA	1745	0	0	117,459	0	0	174,655	0	0	79,750	0	0
Relay LORAN	2075	0	0	2322	0	0	7261	0	0	3857	0	0
CLASS II												
Buried Loops	27	0.3	-230	194	1.1	315	2053	0	0	915	0	0
Reflecting Signs	27	0.3	-315	194	1.1	-35	2053	0	0	915	0	0
Reflecting Road	19	0.3	-490	187	1.2	-12102	1980	0	0	887	0	0
X-Band Post	32	0.3	-305	194	1.1	55	2053	0	0	915	0	0
HF or VHF Post	38	0.3	-285	193	1.1	250	2044	0	0	902	0	0
LF Post	241	0	0	270	0.2	-600	2138	0	0	966	0	0
Light/IR Post	75	0.2	-395	200	1.0	-200	2110	0	0	937	0	0
Buried Magnets	19	0.3	-275	189	1.2	400	1997	0	0	894	0	0
Ultrasonic Post	49	0.2	-390	197	1.1	-40	2085	0	0	927	0	0
Traffic Sensor	27	0.3	-280	193	1.1	320	2042	0	0	911	0	0
CLASS III												
Narrowband FM Phase	2331	0	0	2607	0	0	2916	0	0	2819	0	0
Wideband FM Phase	2769	0	0	3083	0	0	3394	0	0	3297	0	0
Pulse Time of Arrival	166	0.1	-820	185	1.2	-15	207	9.7	6010	207	9.7	6010
Noise Correlation	185	0.1	-810	207	0.9	-220	232	6.8	4090	232	6.8	4090
Direction Finder	1715	0	0	1918	0	0	2182	0	0	1855	0	0
CLASS IV												
Traffic Loops	26	0.3	-320	23	3.2	1475	21	32.4	19,550	21	32.4	19,550
Wayside Radio	234	0	0	209	0.9	-705	187	12.2	-150	187	12.2	-150
Photo/IR Detector	72	0.2	-395	61	2.7	1080	55	28.2	16,200	55	28.2	16,200
Ultrasonic Detector	48	0.2	-395	43	2.9	1230	39	30.2	17,700	39	30.2	17,700

NOTE: A zero entry indicates that no car saving was shown and therefore no cost saving calculation was made.

V. ANALYSIS OF AVM TECHNIQUES FOR UGAC CITIES

To permit a more realistic evaluation of AVM techniques than that provided by the model cities analysis, police department representatives from several cities were invited to participate in a User Group Advisory Committee (UGAC) that would help analyze AVM systems for specific cities. The seven cities selected are all within a reasonable distance of JPL and cover roughly the same range of sizes as the model cities discussed in the previous section. Table 9 lists the cities together with their major characteristics that affect AVM cost and performance.

To provide a required input for AVM performance analysis, the polling times were determined for each of the 36 techniques for each of the UGAC cities. Times were calculated for the three polling techniques (synchronous, volunteer, and random) and for both the maximum and minimum numbers of vehicles deployed. Table 10 summarizes the results of this analysis; complete results are given in Volume 2. The times given in this table are only those for the maximum number of vehicles deployed, and only for single message transmission. The values for redundant transmission were also calculated and are presented in the tables in Volume 2; as in the model cities analysis, they are generally less than 10 percent greater than for single transmission.

The table shows a sharp difference in polling time between the smaller cities and the larger ones, as would be expected. An interesting result is that the higher accuracy made possible by the short polling interval sometimes makes an AVM system show a cost benefit for smaller cities, where normally it would not be expected. This applies particularly to those AVM techniques that use the vehicle-to-base station RF link.

As is pointed out in the footnote to the table, the values for the Relay OMEGA and Relay LORAN techniques are not included in the ranges of polling times shown. These techniques require times for polling individual vehicles which are as much as 200 times longer than those of the other techniques, making them unusable in any practical AVM system.

The major results of the analysis of AVM techniques for the UGAC cities are summarized in Table 11. This table shows the ranges of values calculated for the major groups of AVM techniques (the three types of Class I systems plus Classes II, III, and IV). The smaller value in each column is that for the specific AVM technique in the group or class that shows the lowest value for the group, and the higher value is that for the technique showing the highest value in its group.

Some of the major conclusions that can be drawn from an examination of Table 11 are discussed in the following paragraphs.

A. ACCURACY

As would be expected, the accuracy of a system has a direct effect on whether it indicates a saving in patrol cars. In general, a system with an accuracy worse than about 500 meters is unable to realize any car saving, and the higher accuracy techniques tend to show greater car savings. As the table shows, accuracy can be significantly improved in large cities by adding one or two extra radio channels; this improved accuracy is directly reflected in the five-year cost benefit figures.

B. SYSTEM COST

The table indicates a very wide range of system costs, even for a given city. There is no necessary relation between system costs and five-year cost savings, however; some of the highest-cost systems show the highest five-year savings, but only for large cities. Small cities are able to show five-year savings only for some of the relatively low-cost systems.

C. CITY SIZE

As already indicated, city size has a strong influence on the overall cost effectiveness of AVM systems. The five smaller cities in the UGAC group show no five-year saving for any AVM systems except that Anaheim and Long Beach (which are considerably larger than the smallest cities) show a net

cost saving for the relatively accurate and inexpensive Officer Update and Kinematic Sensor systems. By contrast, San Diego and the four Los Angeles bureaus show a net cost saving for at least one technique in each group except for the wide-area navigation techniques in some cases. This indicates that small and medium cities should look very carefully at any proposals for AVM systems, while large cities should be concerned principally with which system is best for their circumstances.

D. AVM TECHNIQUE

The results presented here are not suitable for selection of a particular AVM technique without further analysis, but they do indicate certain general characteristics. One that is clear from all the tables is that the Relay OMEGA and Relay LORAN techniques are not suitable for any AVM application. This entire group of wide-area navigation techniques shows either no net benefit or one that is probably within the error of the analysis, and consequently does not appear attractive even though the costs are relatively low.

It has already been pointed out that none of the AVM systems appear attractive for small cities, and even where a net benefit is shown (Officer Update and Kinematic Sensor techniques for Anaheim and Long Beach), the amount of the five-year saving is small enough to suggest a much more detailed analysis before any decision is made.

The two groups of techniques that show the most consistent five-year savings are the Officer Update and Kinematic Sensor groups in Class I. This is partly due to their relatively low cost and high accuracy. As noted above, the savings increase dramatically with the addition of extra radio-channels in the large cities (because of the increase in accuracy).

Among the Class II techniques, the Reflecting Road and LF Post techniques consistently show the poorest performance and negative or small five-year savings. Examination of the detailed tables in Volume 2 will show that the most attractive techniques in this group are the Buried Loops, Buried Magnets, and Traffic Sensor techniques.

The relatively expensive Class IV techniques produce the most consistently large five-year savings for large cities, despite their high cost. This results from their negligible polling times and resulting high accuracies. More analysis is needed to verify this result particularly in the light of telephone line rental costs. As noted, the Wayside Radio technique is consistently poor in this group.

Among the Class III techniques (fixed RF sites), only two show acceptable performance and net cost savings. These are the Pulse Time-of-arrival and Noise Correlation techniques, as shown in the detailed table of Volume 2.

All of the above observations relate to the results of this preliminary analysis of AVM systems. Considerably more analysis should be made to provide a basis for determination of whether a given city would profit from an AVM system and which AVM technique would be most suitable in a given case.

Table 9. Characteristics of UGAC Cities

Characteristic	Anaheim	Long Beach	Montclair	Monterey Park	Pasadena	San Diego	L. A. Central	L. A. South	L. A. West	L. A. Valley
Area, square miles	33.5	50.2	5.2	7.3	23	331	57.5	55.2	133.9	215.3
East-West distance, miles	15.8	10	2.3	4.6	6	23.6	9	9	19	23
North-South distance, miles	6	9.6	2.5	3	8	41.2	13	23	18	13.5
Road miles	456	2000	67	101	350	1945	1152	978	1677	2661
Intersections	4800	8000	338	596	1860	13700	9570	6090	9400	15000
Road segments (estimated)	9600	10000	506	826	3720	27400	19140	12180	18800	30000
Cars in fleet	36	61	10	15	35	300	157	165	183	189
Motorcycles in fleet	0	51	0	0	0	52	0	0	0	0
Vehicles per shift										
First shift maximum	14	16	5	14	10	66	60	63	59	72
First shift minimum	14	16	4	4	10	66	50	53	39	61
Second shift maximum	12	16	5	14	10	95	90	94	105	108
Second shift minimum	12	16	4	4	10	95	80	84	94	96
Third shift maximum	19	16	7	14	10	60	100	104	117	121
Third shift minimum	19	16	7	4	10	60	80	84	98	86
Number of dispatchers	1	2	1	1	1		2	2	2	2
Number of wideband antennas*	6	7	3	3	3	23	2	5	7	10
Number of narrowband antennas*	16	21	5	8	7	35	14	23	44	45

* Required number calculated for Class III systems (fixed RF sites)

**Table 10. Polling Times for UGAC Cities;
Time to Poll Maximum Number of Units Deployed, Seconds***

City	Polling Technique					
	Synchronous		Volunteer		Random	
	Min	Max	Min	Max	Min	Max
Anaheim	2.04	2.28	2.12	2.36	4.09	4.36
Long Beach	1.72	1.94	1.79	2.02	3.47	3.69
Montclair	0.75	0.85	0.77	0.86	1.49	1.59
Monterey Park	1.50	1.68	1.54	1.74	2.98	3.17
Pasadena	1.07	1.21	1.11	1.25	2.15	2.29
San Diego	10.20	11.53	10.77	12.10	20.84	22.17
Los Angeles Central	10.73	12.13	11.27	12.67	21.80	23.20
Los Angeles South	11.16	12.62	11.72	13.17	22.67	23.78
Los Angeles West	12.56	14.20	13.18	14.82	25.51	27.14
Los Angeles Valley	12.99	14.68	13.63	15.33	26.38	28.07

*The values given cover the polling time range for all the AVM techniques analyzed except the Relay Omega and Relay Loran techniques; polling times for these techniques are roughly two hundred times those shown above.

Table 11. Summary Data on UGAC Cities AVM Analyses

City	Class I			Class II	Class III	Class IV
	Officer Update	Kinematic Sensors	Wide-area [*] Navigation	Autonomous Signposts	Special RF Sites	Monitored Signposts
<u>ANAHEIM</u>						
System cost range, K\$	176 - 269	261 - 290	210 - 306	1052 - 1930	313 - 822	2342 - 4535
Accuracy range, meters	83 - 94	74 - 108	470 - 3914	71 - 82	177 - 2754	25 - 219
Vehicles saved	0.7	0.6 - 0.7	0 - 0.2	0.4 - 0.7	0 - 0.5	0.5 - 0.8
5-year cost saving, K\$	245	270 - 315	0 or neg	neg to 320	0 or neg	neg
<u>LONG BEACH</u>						
System cost range, K\$	188 - 345	312 - 362	239 - 398	509 - 2525	317 - 1025	11000 - 18735
Accuracy range, meters	82 - 93	64 - 107	389 - 3890	62 - 64	175 - 2930	25 - 224
Vehicles saved	0.9	0.9	0 - 0.3	0.6 - 0.9	0 - 0.7	0.6 - 1.0
5-year cost saving, K\$	165 - 170	125 - 145	0 or neg	neg to 175	0 or neg	neg
<u>MONTCLAIR</u>						
System cost range, K\$	157 - 182	197 - 205	172 - 199	171 - 455	199 - 444	324 - 485
Accuracy range, meters	74 - 88	34 - 103	366 - 3751	15 - 50	164 - 2814	26 - 237
Vehicles saved	0.2 - 0.3	0.2 - 0.4	0	0 - 0.4	0 - 0.1	0 - 0.8
5-year cost saving, K\$	neg	neg	0	0 or neg	0 or neg	0 or neg
<u>MONTEREY PARK</u>						
System cost range, K\$	161 - 200	211 - 223	182 - 221	188 - 701	212 - 491	430 - 711
Accuracy range, meters	74 - 92	34 - 106	367 - 3861	15 - 254	164 - 2911	25 - 237
Vehicles saved	0.2 - 0.6	0.2 - 0.7	0	0 - 0.7	0 - 0.2	0 - 0.8
5-year cost saving, K\$	neg	neg to 20	0	neg to 20	0 or neg	neg to 25
<u>PASADENA</u>						
System cost range, K\$	174 - 264	256 - 285	206 - 301	255 - 3076	257 - 658	1315 - 2358
Accuracy range, meters	79 - 90	40 - 104	381 - 3810	40 - 250	172 - 2864	25 - 226
Vehicles saved	0.5	0.5 - 0.6	0 - 0.1	0.3 - 0.6	0 - 0.4	0.3 - 0.6
5-year cost saving, K\$	neg	neg	0 or neg	neg	0 or neg	neg
<u>SAN DIEGO, 1 Channel</u>						
System cost range, K\$	255 - 1030	785 - 987	420 - 1211	809 - 26969	411 - 2895	10917 - 19840
Accuracy range, meters	245 - 395	243 - 390	411 - 4192	233 - 400	187 - 3167	23 - 207
Vehicles saved	2.2 - 2.7	2.3 - 2.8	0 - 2.0	0 - 2.9	0 - 4.5	3.0 - 6.3
5-year cost saving, K\$	1485 - 1525	1375 - 1540	0 - 880	neg to 1575	0 - 2250	neg to 2565 ⁺
<u>SAN DIEGO, 2 Channels</u>						
Accuracy range, meters	82 - 138	79 - 130	393 - 4004	78 - 265	187 - 3024	23 - 207
Vehicles saved	3.6 - 5.2	3.5 - 5.2	0 - 2.2	2.7 - 5.2	0 - 4.5	3.0 - 6.3
5-year cost saving, K\$	3285 - 3375	3100 - 3340	0 - 1035	neg to 3400	0 - 2250	neg to 2565 ⁺

^{*} The figures for the Relay Omega and Relay Loran techniques are not included in these ranges; they are too far from the others in this group to be of practical interest.

⁺ Only one of these techniques, Wayside Radio, is negative; the others are of the same order as the maximum given.

Table 11. Summary Data on UGAC Cities AVM Analyses (contd)

City		Class I		Class II	Class III	Class IV
	Officer Update	Kinematic Sensors	Wide-Area Navigation*	Autonomous Signposts	Special RF Sites	Monitored Signposts
<u>LOS ANGELES CENTRAL</u>						
System cost range, K\$	212 - 617	513 - 610	318 - 727	597 - 18843	111 - 1230	7031 - 12922
Accuracy range, meters	201 - 410	200 - 405	408 - 4199	193 - 415	185 - 3173	23 - 209
Vehicles saved	0 - 1.4	0 - 1.4	0	0 - 1.5	0 - 1.6	1.1 - 5.7
5-year cost saving, K\$	455 - 535	430 - 515	0	neg to 540	0 - 270	neg to 3065 ⁺
L. A. CENTRAL, 2 Channels						
Accuracy range, meters	95 - 209	95 - 205	396 - 4079	92 - 271	185 - 3083	23 - 209
Vehicles saved	1.0 - 2.5	1.0 - 2.5	0	0 - 2.5	0 - 1.6	1.1 - 5.7
5-year cost saving, K\$	1280 - 1360	1105 - 1340	0	neg to 1375	0 - 270	neg to 3065 ⁺
L. A. CENTRAL, 3 Channels						
Accuracy range, meters	82 - 139	67 - 137	390 - 4011	65 - 265	185 - 3031	23 - 209
Vehicles saved	2.5 - 3.1	2.4 - 3.1	0	0 - 3.3	0 - 1.6	1.1 - 6.3
5-year cost saving, K\$	1730 - 1810	1630 - 1790	0	neg to 1975	0 - 270	neg to 3065 ⁺
<u>LOS ANGELES SOUTH</u>						
System cost range, K\$	214 - 641	497 - 631	345 - 754	461 - 11308	431 - 1407	3605 - 6829
Accuracy range, meters	213 - 425	212 - 420	409 - 4206	204 - 429	186 - 3179	23 - 209
Vehicles saved	0 - 1.2	0 - 1.3	0	0 - 1.4	0 - 1.6	1.0 - 6.5
5-year cost saving, K\$	375 - 385	275 - 400	0	neg to 465	0 - 245	neg to 3635 ⁺
L. A. SOUTH, 2 channels						
Accuracy range, meters	105 - 217	105 - 214	397 - 4086	96 - 271	186 - 3088	23 - 209
Vehicles saved	0.5 - 2.5	0.6 - 2.5	0	0 - 2.6	0 - 1.6	1.0 - 6.5
5-year cost saving, K\$	1275 - 1360	1175 - 1340	0	0 - 1375	0 - 245	neg to 3635 ⁺
L. A. SOUTH, 3 Channels						
Accuracy range, meters	82 - 144	71 - 142	391 - 4017	70 - 266	186 - 3036	23 - 209
Vehicles saved	2.6 - 2.9	2.4 - 2.9	0	0 - 3.1	0 - 1.6	1.0 - 6.5
5-year cost saving, K\$	1500 - 1660	1475 - 1640	0	neg to 1825	0 - 245	neg to 3635 ⁺
<u>LOS ANGELES WEST</u>						
System cost range, K\$	222 - 695	560 - 683	331 - 813	602 - 18545	348 - 1830	10636 - 18462
Accuracy range, meters	157 - 475	156 - 469	404 - 4227	149 - 465	183 - 3194	22 - 201
Vehicles saved	0 - 2.0	0 - 2.0	0 - 0.8	0 - 2.0	0 - 3.5	1.7 - 7.6
5-year cost saving, K\$	900 - 985	830 - 960	neg to 30	neg to 1000	0 - 1615	neg to 4060 ⁺
L. A. WEST, 2 channels						
Accuracy range, meters	80 - 244	77 - 241	392 - 4106	74 - 273	183 - 3103	22 - 201
Vehicles saved	2.2 - 2.5	2.2 - 2.6	0 - 0.9	1.5 - 2.8	0 - 3.5	1.7 - 7.6
5-year cost saving, K\$	1200 - 1360	1160 - 1365	neg to 105	neg to 1600	0 - 1615	neg to 4060 ⁺
L. A. WEST, 3 channels						
Accuracy range, meters	81 - 163	51 - 160	386 - 4037	51 - 267	183 - 3051	22 - 212
Vehicles saved	2.3 - 4.4	2.2 - 4.4	0 - 0.9	1.5 - 4.6	0 - 3.5	1.7 - 7.6
5-year cost saving, K\$	2700 - 2785	2630 - 2760	neg to 105	neg to 2950	0 - 1615	neg to 4060 ⁺

Table 11. Summary Data on UGAC Cities AVM Analyses (contd)

City	Class I			Class II	Class III	Class IV
	Officer Update	Kinematic Sensors	Wide-Area Navigation*	Autonomous Signposts	Special RF Sites	Monitored Signposts
<u>LOS ANGELES VALLEY</u>						
System cost range, K\$	225 - 684	547 - 701	337 - 835	829 - 29436	378 - 1871	14225 - 25281
Accuracy range, meters	246 - 490	244 - 482	411 - 4233	236 - 497	187 - 3199	23 - 207
Vehicles saved	0 - 2.5	0 - 2.5	0 - 1.3	0 - 2.6	0 - 4.6	2.8 - 8.0
5-year cost saving, K\$	1275 - 1360	1155 - 1285	neg to 400	neg to 1450	0 - 2435	neg to 3690 ⁺
L. A. Valley, 2 channels						
Accuracy range, meters	122 - 253	121 - 249	400 - 4112	116 - 273	187 - 3107	22 - 207
Vehicles saved	3.3 - 3.6	3.3 - 3.6	0 - 1.4	3.3 - 3.8	0 - 4.6	2.8 - 7.6
5-year cost saving, K\$	2025 - 2185	1980 - 2160	neg to 475	neg to 2350	0 - 2435	neg to 3690 ⁺
L. A. Valley, 3 channels						
Accuracy range, meters	83 - 168	80 - 165	393 - 4043	77 - 268	187 - 3055	22 - 207
Vehicles saved	3.6 - 5.2	3.5 - 5.2	0 - 1.4	2.4 - 5.4	0 - 4.6	2.8 - 7.6
5-year cost saving, K\$	3300 - 3385	3180 - 3310	neg to 475	neg to 3465	0 - 2435	neg to 3690 ⁺
* The figures for the Relay Omega and Relay Loran techniques are not included in these ranges; they are too far from the others in this group to be of practical interest. ⁺ Only one of these techniques, Wayside Radio, is negative; the others are of the same order as the maximum shown.						

VI. ANALYSIS PROCEDURES

A. COMPUTER PROGRAMS

Several computer programs were developed to generate the data presented in the tables of Volume 2 (and summarized in this volume). Some of these, such as the program used to compute system costs, are straightforward programs to perform the routine addition, subtraction, and multiplication. Others, primarily those dealing with polling performance and accuracy calculations, required more sophisticated mathematical processing to handle the probabilistic nature of these calculations. These programs are described in Volume 2, with a detailed account of the analytical techniques for estimating system accuracy in Part Three.

B. AM STATIONS AND BURIED LOOPS TECHNIQUE ANALYSIS

The techniques of using existing AM stations around a city to provide location information to vehicles by means of phase comparison of their carrier signals was developed and analyzed as part of this project. A detailed description of the principle of operation, plus a mathematical treatment of its accuracy and a description of the computer programs developed for analyzing the system will be found in Volume 2, Part Four. A similar treatment of the buried loops system, also conceived as part of this project, is also given in Volume 2, Part Four.

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